Shock Wave Data for Minerals

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1. INTRODUCTION

Shock compression of the materials of planetary interiors yields data, which upon comparison with density-pressure and density-sound velocity profiles of both terrestrial planetary mantles and cores [4,5,94], as well as density profiles for the interior of the major planets [148], constrain internal composition and temperature. Other important applications of shock wave data and related properties are found in the impact mechanics of terrestrial planets and the solid satellites of the terrestrial and major planets. Significant processes which can, or have been, studied using shock wave data include: (1) the formation of planetary metallic cores during accretion [169,192], and (2) the production of a shock-melted "magma ocean" and concurrent impact volatilization versus retention of volatiles during accretion [1]. Also of interest are the shock-induced chemical reactions between meteoritic components (e.g. H_2O and Fe: [111]). The formation of primitive atmospheres, for example, containing a large fraction of H_2O and CO_2 is also addressable using shock wave and other thermodynamic data for volatile-bearing minerals (e.g. [110,112]). A related application of both shock

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compression and isentropic release data for minerals [13,14] is in the mechanics of both the continued bombardment and hence cratering on planetary objects through geologic time [170], as well as the effects of giant impacts on the Earth [183,185]. Finally, recovery and characterization of shock-compressed materials have provided important insights into the nature of shock deformation mechanisms and, in some cases, provided physical data on the nature of either shock-induced phase changes or phase changes which occur upon isentropic release from the high-pressure shock state (e.g., melting) [193,194].

As indicated for the data summary of Table 1, a very large data set exists describing the Hugoniot equation of state of minerals. Whereas some earlier summaries have provided raw shock data [47,121,213], the present summary provides fits to shock wave data. Earlier summaries providing fits to data are given by Al'tshuler et al. [24] and Trunin [203].

Hugoniot data specify the locus of pressure-density (or specific volume) states which can be achieved by a mineral from some initial state with a specified initial density. An analogous summary for rocks, usually described as a mixture of minerals are given in Chapter 3-4.

Three pressure units are commonly in use in the shock wave literature: kilobar (kbar), gigapascal (GPa), and megabar (Mbar). These are equal to 10^9, 10^{10}, and 10^{12} dyne/cm^2, respectively, or 10^8, 10^9, and 10^{11} pascals in SI units.

2. SHOCK WAVE EQUATION OF STATE

The propagation of a shock wave from a detonating explosive or the shock wave induced upon impact of a flyer plate accelerated, via explosives or with a gun, result in nearly steady waves in materials. For steady waves a shock velocity U_S with respect to the laboratory frame can

be defined. Conservation of mass, momentum, and energy across a shock front can then be expressed as

$$\rho_1 = \rho_0 (U_S - u_0)/(U_S - u_1) \quad (1)$$

$$P_1 - P_0 = \rho_0 (u_1 - u_0)(U_S - u_0) \quad (2)$$

$$E_1 - E_0 = (P_1 + P_0)(1/\rho_0 - 1/\rho_1)/2 = 1/2\,(u_1 - u_0)^2 \quad (3)$$

where ρ, u, P, and E are density, particle velocity, shock pressure, and internal energy per unit mass and, as indicated in Fig. 1, the subscripts o and 1 refer to the state in front of and behind the shock front, respectively. In Table 1, shock velocity and particle velocity are designated as U_S and U_p. Equations (1)-(3) are often called the Rankine-Hugoniot equations. It should be understood that in this section pressure is used in place of stress in the indicated wave propagation direction. In actuality, stress in the wave propagation direction is specified by Eq. (2). A detailed derivation of Eqs. (1), (2), and (3) is given in Duvall and Fowles [70]. Equation (3) also indicates that the material achieves an increase in internal energy (per unit mass) which is exactly equal to the kinetic energy per unit mass.

In the simplest case, when a single shock state is achieved via a shock front, the Rankine-Hugoniot equations involve six variables (U_S, u_1, ρ_0, ρ_1, $E_1 - E_0$, and P_1); thus, measuring three, usually U_S, u_1, and ρ_0, determines the shock state variables ρ_1, E_1-E_0 and P_1. The key assumption underpinning the validity of Eqs. (1)-(3) is that the shock wave is steady, so that the rise time τ_S, is short compared to the characteristic time for which the high pressure, density, etc. are constant (see Fig. 1). Upon driving a shock of pressure P_1 into a material, a final shock state is achieved which is described by Eqs. (1)-(3). This shock state is shown in Fig. 2, in relation to other thermodynamic paths, in the pressure-volume plane. Here $V_0 = 1/\rho_0$ and $V = 1/\rho$. In the case of the isotherm and isentrope, it is possible to follow, as a thermodynamic path, the actual isothermal or isentropic curve to achieve a

state on the isotherm or isentrope. A shock, or Hugoniot, state is different, however. The Hugoniot state (P_1,V_1) is achieved via a a shock front. The initial and final states are connected by a straight line called a Rayleigh line (Fig. 2). Thus successive states along the Hugoniot curve cannot be achieved, one from another, by a shock process. The Hugoniot curve itself then just represents the locus of final shock states corresponding to a given initial state.

It has long been recognized that the kinematic parameters measured in shock wave experiments U_S and U_p can empirically be described in regions where a substantial phase change in the material does not occur as:

$$U_S = C_0 + S\,U_p \qquad (4)$$

As further discussed in several review articles on shock compression [22,59,136], and a recent book [40], Hugoniot data for minerals and other condensed media may be described over varying ranges of pressure and density in terms of a linear relation of shock and particle velocity in Table 1. This table was assembled using the *Microsoft Excel*, version 3.0, (Redmond, WA 1993) program and the least-square fits to the shock wave data with standard errors were derived by using the LINEST function. The equations employed for line slopes and intercepts are identical to those given in Bevington [46] (Eq. 6-9, p. 104; Eq. 6-21, p. 114 for errors in slopes; and Eq. 6-22, p. 114 for errors in intercepts).

The U_S-U_p data for a wide range of minerals are given in Table 1. Here C_0 is the shock velocity at infinitesimally small particle velocity, or the ambient pressure bulk sound velocity which is given by

$$C_0 = \sqrt{K_S/\rho_0}\,, \qquad (5)$$

where K_S is the isentropic bulk modulus,

$K_S = -V\ (dP/dV)_S$ in the absence of strength effect (see Sect. 3). Upon substituting Eq. 4 into Eq. 2, and denoting the shock pressure as P_H, this is given by:

$$P_H = \rho_o U_p\ (C_o + S\ U_p) \tag{6}$$

Thus, from the form of Eq. 6, shock pressure is given as the sum of a linear and quadratic term in particle velocity, based on the data of Table 1. A pressure-volume relation can be obtained by combining Eq. 6 with Eq. 1 to yield:

$$P_H = \rho_o\ C_o^2\ \eta\ /(1-S\eta)^2 \tag{7}$$

where

$$\eta = 1 - V/V_o = U_p\ /U_s. \tag{8}$$

Eq. 7 is often called the "shock wave equation of state" since it defines a curve in the pressure-volume plane.

The isentropic pressure can be written (e.g. [93,98,171])by an expression analogous to Eq. 7 as a series

$$P_s = \rho_o\ C_o^2\ (\eta + 2S\eta^2 + \cdots), \tag{9}$$

which upon differentiation yield the isentropic bulk modulus

$$K_S = \rho_o\ C_o^2\ (1 + (4S-1)\ \eta + \cdots) \tag{10}$$

The analogous bulk modulus along the Hugoniot is:

$$K_H = -V\ (\partial P/\partial V)_H. \tag{11}$$

The isentrope and the Hugoniot and isentropic bulk modulus are related via:

$$K_S = K_H + \left(\frac{\gamma}{2}\right)\left[P_H - K_H\ \eta/(1-\eta)\right] - \left[P_H - P_S\right]\left[\gamma + 1 - q_o\ (1 - q'\eta + \cdots)\right] \quad (12)$$

Here we assume a volume dependence of the Gruneisen parameter

$$\gamma = V\,(\partial P/\partial E)_V = \gamma_o\,(V/V_o)^q, \quad (13)$$

where

$$q = d\,\ell n\,\gamma/d\,\ell n\,V \text{ and } q' = d\,\ell nq/d\ell n\,V \quad (14)$$

γ_o is the Grüneisen parameter under standard pressure and temperatures and is given by

$$\gamma_o = \alpha\,K_T\,V_o/C_v = \alpha\,K_s V_o/C_p, \quad (15)$$

where α is the the thermal expansion coefficient, K_T is the isothermal bulk modulus and C_p and C_v are the specific heat at constant pressure and volume. We note that the P_S and P_H can be related by assuming the Mie-Grüneisen relation

$$P_H - P_S = \frac{\gamma}{V}(E_H - E_S), \quad (16)$$

if γ is independent of temperature, where $E_H = E_1 - E_0$ is given by Eq. 3 and E_S is given by

$$E_S = -\int_{V_o}^{V} P_S dV. \quad (17)$$

Because the Grüneisen ratio relates the isentropic pressure, P_S, and bulk modulus, K_S, to the Hugoniot pressure, P_H, and Hugoniot bulk modulus, K_H, it is a key equation of state parameter.

The shock-velocity particle relation of Table 1 can be used to calculate the shock pressure when two objects impact. If (A) the flyer plate and (B) the target are known and expressed in the form of Eq. (7), the particle velocity u_1 and pressure P_1 of the shock state produced upon impact of a flyer plate at velocity u_{fp} on a stationary target may be calculated from the solution of the equation equating the shock pressures in the flyer and driver plate:

$$\rho_{oA}\,(u_{fp} - u_1)(C_{oA} + S_A\,(u_{fp} - u_1)) = \rho_{oB}\,u_1\,(C_{oB} + S_B\,u_1). \tag{18}$$

That is;

$$u_1 = (-b - \sqrt{b^2 - 4ac})/2a, \tag{19}$$

where

$$a = S_A\,\rho_{oA} - \rho_{oB}\,S_B, \tag{20}$$

$$b = C_{oA}\,\rho_{oA} - 2S_A\,\rho_{oA}\,u_{fp} - \rho_{oB}\,C_{oB}, \tag{21}$$

and

$$c = u_{fp}\,(C_{oA}\,\rho_{oA} + S_A\,\rho_{oA}\,u_{fp}). \tag{22}$$

3. SHOCK-INDUCED DYNAMIC YIELDING AND PHASE TRANSITIONS

Both dynamic yielding and phase transitions give rise to multiple shock wave profiles when pressure or particle velocity versus time is recorded. Virtually all nonporous minerals and rocks in which dynamic compression has been studied demonstrate phenomenon related to dynamic yielding, in which materials transform from finite elastic strain states to states in which irreversible deformation has occurred. Moreover, most minerals and a large number of

compounds, elements, and organic materials demonstrate shock-induced phase changes.

The dynamic yield point under shock compression, the Hugoniot elastic limit, or HEL, is defined as the maximum shock pressure a material may be subjected to without permanent, massive, microscopic rearrangement taking place at the shock front. As shown in Fig. 3a, the shock velocity of the HEL state remains nearly constant and for non-porous media is usually equal to the longitudinal elastic wave velocity. Viscoelastic polymeric media generally do not display the HEL phenomenon. We denote five regimes in Fig. 3 for the case of dynamic yielding and phase transition and the available shock wave data are separately fit to linear relations in these regimes in Table 1. For some minerals there are more than four regimes indicated, for reasons such as crystallographic control of compression at low pressures (such as O_a,O_b for quartz), and for more than one high-pressure state (such as 4a, 4b, and 4c for halite).

The crystallographic or atomistic level nature of shock-induced phase changes varies from simple average coordination changes observed in various liquids, ionization and debonding in non-metallic fluids, electronic transitions in metal and non-metals, changes in crystal structure in solid materials, and transition from the solid to the fluid state.

In the case of a phase change, the pressure along the isentrope P_S at the volume V_1 corresponding to a Hugoniot state (P_1,V_1) is given by

$$\frac{P_1}{2}(V_{OO} - V_1) = -\int_{V_O}^{V_1} PdV + \frac{V_1}{\gamma}(P_1 - P_S) + E_{TR} \qquad (23)$$

where the left-hand side is the Rankine-Hugoniot energy, and the first and second terms on the right represent the gain in the internal energy along the paths 1 and 2 of Fig. 2 Here V_{OO} is the specific volume of the initial material and V_O the specific volume of the shock-induced high-pressure phase, or the intrinsic volume of the sample if the

initial state is distended. Also E_{TR} is the energy of transition to the high-pressure phase at STP. In the case of no phase change, $E_{TR} = 0$. For zero initial porosity $V_{OO} = V_O$. The unknown parameter in Eq. 23 is P_S, which is implicit in the first integral term on the right-hand side and explicit in the second term. The second term is obtained by using the definition of the Gruneisen parameter (Eq. 13) to calculate the change in energy associated with the pressure difference (P_1-P_S) at constant volume.

4. SHOCK TEMPERATURES

For many condensed media, the Mie-Gruneisen equation of state, based on a finite-difference formulation of the Gruneisen parameter (Eq. 16), can be used to describe shock and postshock temperatures. The temperature along the isentrope [224] is given by

$$T_S = T_i \exp\left[-\int_{V_a}^{V_b}\left(\frac{\gamma}{V}\right) dV\right] \tag{24}$$

where T_i is the initial temperature. For the principal isentrope centered at room temperature, $T_i = T_O$, $V_a = V_O$, initial volume, and $V_b = V$, compressed volume. For the calculation of postshock temperatures $T_i = T_H$, the Hugoniot temperature, $V_a = V_H$, the volume of the shock state, and $V_b = V_{OO}'$, the postshock volume corresponding to the postshock temperature. For shock compression to a volume V, P_S is first obtained by using Eq. 23; then T_S, the isentropic compression temperature at volume V, may be calculated by using Eq. 24. Finally, using Eq. 16, the shock temperature T_H is given by

$$\frac{V}{\gamma}(P_H - P_S) = \int_{T_S}^{T_H} C_V \, dT \tag{25}$$

It is useful to carry out both postshock and shock temperature measurements as they provide complementary information for the thermal equation of state, that is, γ, as well as C_V. Minerals for which shock temperatures have been (usually via radiative techniques) are so indicated in Table 1.

In the case of molecular fluids such as water, a formulation based on the near constancy of C_P at constant pressure is used [41,167].

Although there have been few data collected, postshock temperatures are very sensitive to the models which specify γ and its volume dependence, in the case of the Gruneisen equation of state [49,164,165]. In contrast, the absolute values of shock temperatures are sensitive to the phase transition energy E_{TR} of Eq. 23, whereas the slope of the T_H vs. pressure curve is sensitive to the specific heat.

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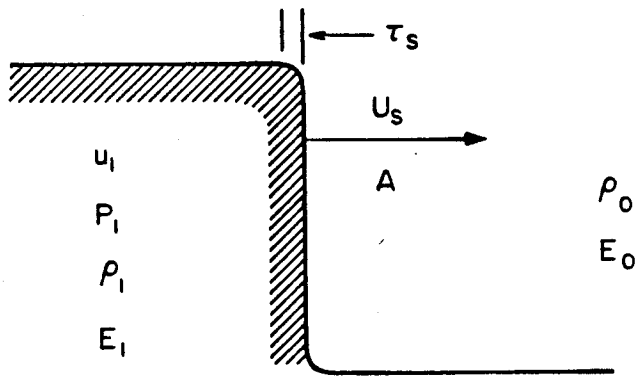
FIGURE CAPTIONS

FIG. 1. Profile of a steady shock wave, rise time τ_S, imparting a particle velocity u_1 pressure P_1, and internal energy density E_1, propagating with velocity U_S into material that is at rest at density ρ_0 and internal energy density E_0.

FIG. 2. Pressure-volume compression curves. For isentrope and isotherm, the thermodynamic path coincides with the locus of states, whereas for shock, the thermodynamic path is a straight line to point P_1,V_1, on the Hugoniot curve, which is the locus of shock states.

FIG. 3. Sketch of shock velocity-particle relation (a) and corresponding pressure-volume Hugoniot curves (b) for a mineral which undergoes dynamic yielding and a phase change.

0: compression up to the Hugoniot Elastic Limit (HEL)
1: transition via dynamic yielding to a quasi-hydrostatic state
2: low pressure state
3: mixed region
4: high pressure state



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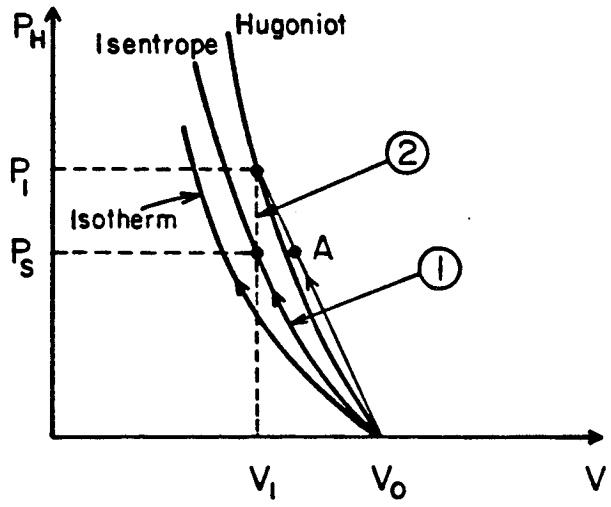

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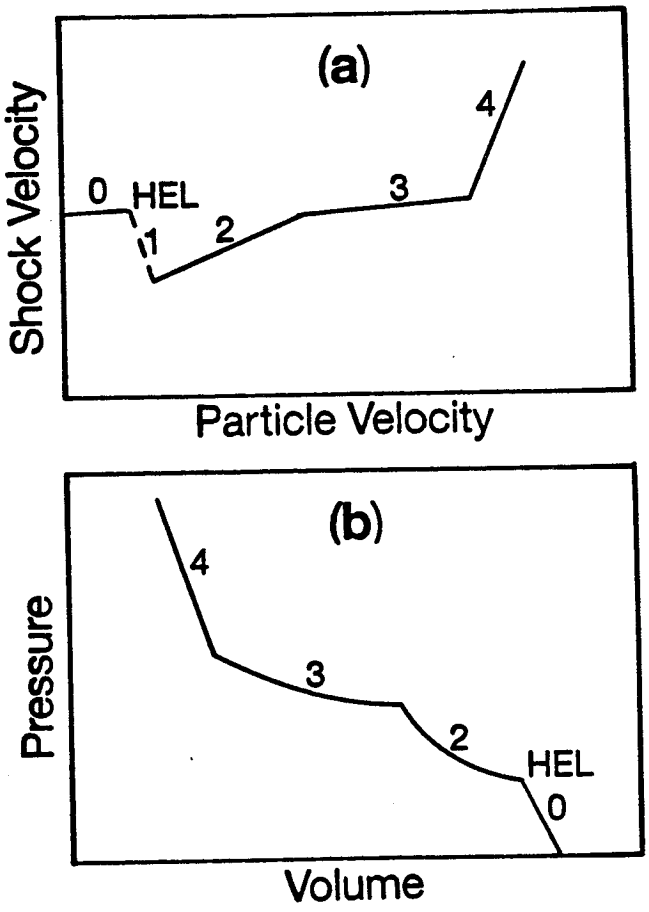

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TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Gases:											
Air[c]	(mixture)	0.884	2.28	--	1.20	--	4.317	5.788	2	2	
			4.25	--	0.85	--	5.788	7.379	4	2	[147]
Nitrogen plus Oxygen[c]	1:1 N_2+O_2	0.945	1.83	0.11	1.26	0.03	2.235	3.785	2	6	[179]
Nitric Oxide[e]	NO	1.263	3.76	0.06	0.98	0.02	2.01	3.245	2	7	[179]
Ammonia[i]	NH_3	0.715	2.45	0.19	1.34	0.04	1.01	7.566	2	12	[83,121,140]/[159]
Argon[k]	Ar	0.0013	0.71	0.10	1.041	0.018	1.73	7.81	2	25	[58,71,84]
Argon[f]	Ar	0.919	1.04	0.06	1.36	0.02	1.59	4.04	2	6	[214]
Argon[l]	Ar	1.026	1.1	0.2	1.45	0.07	1.42	4.10	2	7	[213]
Argon[c]	Ar	1.401	1.01	0.10	1.79	0.08	0.301	1.35	2	9	
			1.28	0.06	1.58	0.02	1.32	3.758	3	24	
			3.04	0.14	1.09	0.03	3.65	6.451	4	10	[80,121,146,180, 214] / [80,221]
Argon[c]	Ar	1.65	0.88	0.15	2.00	0.11	0.56	1.85	2	8	
			1.9	0.3	1.46	0.10	1.85	3.60	3	7	
			2.5	0.3	1.29	0.07	3.60	4.60	4	3	[64,109,121,189]
Carbon Dioxide[i]	CO_2	1.173	1.54	0.09	1.44	0.03	1.585	3.765	2	16	
			3.3	0.4	1.01	0.07	4.549	6.264	4	3	[147,178]

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Carbon Dioxide[h]	CO_2	1.541	1.99	0.08	1.56	0.03	1.03	3.68	2	3	
			3.27	--	1.21	--	3.68	4.79	4	2	[233]
Carbon Monoxide[c]	CO	0.807	1.54	--	1.40	--	1.692	2.471	2	2	
			2.59	0.04	0.974	0.010	2.471	5.608	3	3	
			1.3	0.3	1.21	0.04	5.608	7.92	4	4	[150]
Deuterium[b]	D_2	0.167	1.7	0.6	1.29	0.12	3.678	6.263	2	8	
			2.4	0.3	1.17	0.03	6.263	9.014	3	4	[63,144]
Helium[a]	He	0.123	0.674	0.011	1.366	0.002	2.47	9.39	2	3	[145]
Hydrogen[b]	H_2	0.071	1.128	0.006	1.829	0.013	0	1.105	1	5	
			1.49	0.08	1.51	0.03	1.105	3.080	2	3	
			2.38	0.19	1.23	0.03	3.080	9.962	4	10	[63,144,215]
Hydrogen[a]	H_2	0.089	1.80	0.12	1.89	0.09	0.801	1.525	2	4	[109]
Methane[d]	CH_4	0.423	2.19	--	1.35	--	2.222	3.568	2	2	
			2.87	0.09	1.166	0.014	3.568	8.341	4	4	[150]
Nitrogen[k]	N_2	0.0013	0.38	0.02	1.038	0.004	3.80	8.99	2	10	[57]
Nitrogen[c]	N_2	0.811	0.94	0.10	1.83	0.09	0	1.57	1	9	
			1.14	0.18	1.59	0.08	1.51	3.26	2	15	
			2.1	0.3	1.26	0.06	3.26	5.23	3	24	
			4.0	0.2	0.88	0.04	5.2	8.63	4	12	[60,61,62,121,146, 149,179,213,233] / [149,160,221]
Oxygen[c]	O_2	1.202	1.60	0.16	1.45	0.06	2.06	2.98	2	9	
			2.35	0.10	1.22	0.02	2.91	6.766	4	16	[121,146,223]
Xenon[k]	Xe	0.012	0.2	0.4	1.15	0.13	1.58	3.33	1	4	
			1.5	0.5	0.74	0.13	3.13	4.11	3	6	
			0.04	0.3	1.14	0.05	4.11	7.69	2	7	
			1.8	0.5	0.93	0.05	7.69	11.1	4	3	[71,81,216]

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Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Xenon[g]	Xe	3.006	1.33	0.16	1.33	0.09	1.185	2.51	1	8	
			1.7	-	1.1	-	2.51	2.7	3	2	
			1.49	0.15	1.21	0.05	2.7	3.82	2	8	
			1.94	0.14	1.09	0.03	3.82	5.502	4	3	[151,212,213] /[161,212]
Elements:											
Antimony	Sb	6.695	3.2	-	-0.8	-	0	0.311	1	2	
			2.62	0.02	0.95	0.03	0.311	0.997	2	6	
			2.03	0.07	1.61	0.04	0.989	2.699	4	13	[121,126,217,227]
Bismuth	Bi	9.817	2.17	0.06	-1.0	0.5	0	0.32	1	17	
			1.08	0.06	2.20	0.07	0.32	1.183	2	30	
			2.01	0.04	1.358	0.019	1.183	4.45	4	21	[30,68,89,113,121, 131,166,217,226]
Carbon:											
Graphite	C	0.4665	0.4	0.3	1.14	0.06	2.114	6.147	2	6	[121]
Graphite	C	1.000	0.79	0.12	1.30	0.03	0.772	5.617	2	36	[121]
Graphite	C	1.611	1.75	0.09	1.42	0.05	0.911	4.22	2	60	[82,121,133,213, 217]
Graphite	C	1.794	2.04	0.14	1.66	0.08	0	2.563	2	30	
			4.2	0.5	0.71	0.18	2.372	3.08	3	19	
			1.9	0.3	1.49	0.07	3.069	5.42	4	41	[82,121,133,213, 217]
Graphite	C	2.205	3.11	0.07	4.7	0.2	0.012	0.41	1	12	
			4.19	0.05	1.83	0.04	0.404	1.9	2	77	
			7.5	0.3	0.21	0.11	1.89	3.316	3	24	
			3.92	0.06	1.331	0.008	3.119	28.38	4	22	[58,65,82,121,126, 133,162,217]
Diamond	C	1.90	1.2	0.2	1.73	0.05	2	6.5	2	5	[153]

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Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Diamond	C	3.191	7.74	0.05	1.456	0.019	1.364	3.133	2	3	[121]
Diamond[9]	C	3.51	12.16	--	1	--	2	8.5	2	--	[153]
Glassy Carbon	C	1.507	2.72	0.11	1.12	0.03	0	5.8	2	45	[82,121,181]
Carbon Foam	C	0.435	0.85	0.09	0.88	0.05	0.815	2.301	2	20	[121]
			-0.35	0.12	1.34	0.02	2.119	6.734	4	83	
Carbon Fibers	C	1.519	1.18	0.09	1.73	0.06	0.924	2.361	2	5	[121]
			2.52	0.10	1.14	0.03	2.361	5.041	4	15	
Cobalt	Co	2.594	-0.15	0.06	1.602	0.017	0.651	6.39	2	11	[209]
Cobalt	Co	4.15	0.05	0.03	1.863	0.014	0.615	3.63	2	8	[209]
Cobalt	Co	5.533	0.42	0.04	2.11	0.02	0.293	2.89	2	10	[209]
			1.38	0.08	1.76	0.02	2.89	5.2	4	4	
Cobalt	Co	8.82	4.53	--	1.77	--	0	0.482	1	2	[24,121,126,131, 166,217,226]
			4.77	0.02	1.285	0.014	0.482	2.297	2	17	
			3.98	0.13	1.66	0.04	2.289	4.32	4	4	
Copper	Cu	1.909	0.03	0.08	1.361	0.009	0.661	26.1	2	27	[24,209]
Copper	Cu	2.887	0.37	0.08	1.406	0.015	1.15	17.25	2	28	[24,121,209]
Copper	Cu	3.57	0.03	0.02	1.675	0.008	0.63	3.96	2	6	[209]
Copper	Cu	4.475	1.35	--	-2.02	--	0	0.315	1	2	[56,121,134,136, 204,209]
			0.15	0.05	1.87	0.03	0.315	2.944	2	14	
			1.9	0.3	1.33	0.05	2.944	9.56	4	8	

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Copper	Cu	6.144	2.73	0.11	-1.7	0.8	0	0.534	1	14	
			0.87	0.07	1.97	0.04	0.534	3.365	2	39	
			3.2	0.4	1.27	0.07	3.327	8.77	4	5	[56,121,128,134, 136,172,204,209, 217]
Copper	Cu	7.315	3.15	0.14	-0.4	0.2	0	0.701	1	3	
			1.73	0.07	1.94	0.04	0.669	3.063	2	18	[56,121,126,128, 134,136]
Copper	Cu	7.90	3.39	0.04	-0.06	0.08	0	0.646	1	3	
			2.29	0.06	1.90	0.03	0.627	2.969	2	18	[56,121,127,134, 136]
Copper	Cu	8.931	3.982	0.014	1.460	0.006	0	12.1	2	315	[22,24,25,28,29,30, 90,121,126,131, 134,136,139,141, 143,166,172,184, 205,213,217,226]
Germanium	Ge	5.328	5.93	0.19	-1.8	0.2	0.0775	1.226	1	17	
			1.98	0.10	1.63	0.04	1.226	3.188	2	46	[79,121,126,136, 213]
Gold	Au	19.263	2.95	0.03	1.81	0.07	0	0.71	1	5	
			3.08	0.04	1.546	0.019	0.71	3.52	2	11	[24,100,121,131, 166,217,226]
Indium	In	7.281	2.54	0.05	1.49	0.03	0.56	2.932	2	15	
			5.48	--	0.47	--	2.932	4.87	4	2	[24,121,166,217, 226]
Iodine	I_2	4.902	1.62	0.03	1.25	0.04	0.49	0.9	1	5	
			1.34	0.04	1.59	0.02	0.9	2.66	2	38	
			2.4	0.3	1.17	0.08	2.65	4.73	4	13	[125,213]
Iridium	Ir	22.54	3.81	0.05	1.76	0.10	0	0.933	1	6	
			4.37	0.07	1.15	0.05	0.933	1.629	3	4	
			3.36	0.09	1.76	0.04	1.629	3.09	4	3	[24,121,136]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_o (km/sec)	error ΔC_o (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Iron	Fe	2.633	-0.04	0.08	1.63	0.04	0.646	3.27	2	6	
			1.8	0.3	1.28	0.03	3.27	21.54	4	8	[204,209]
Iron	Fe	3.359	0.23	0.09	1.67	0.04	0.644	5.52	2	24	[121,134,136,204]
Iron	Fe	4.547	0.57	0.09	1.88	0.04	0.591	3.59	2	33	
			2.4	0.3	1.38	0.05	3.58	9.1	4	6	[121,134,136,204, 209]
Iron	Fe	5.783	3.15	0.10	-1.7	0.6	0	0.537	1	12	
			1.17	0.03	1.98	0.04	0.537	0.941	2	4	
			0.01	0.09	3.22	0.08	0.941	1.249	3	3	
			2.25	0.09	1.61	0.03	1.565	4.95	4	10	[31,121,134,136, 172,213]
Iron	Fe	6.972	4.1	--	-1.5	--	0	0.569	1	2	
			2.4	0.2	1.3	0.3	0.569	0.85	2	5	
			1.2	0.3	2.8	0.2	0.85	1.453	3	4	
			2.77	0.08	1.71	0.04	1.427	3.131	4	15	[121,134,136]
Iron	Fe	7.853	5.85	0.12	-1.7	0.8	0	0.573	1	16	
			3.48	0.05	1.91	0.05	0.763	1.433	2	42	
			3.94	0.03	1.584	0.013	1.413	4.55	4a	97	
			5.36	0.07	1.302	0.008	4.50	21.73	4b	18	[24,25,29,30,31,33, 108,121,126,131, 132,134,136,138, 162,166,172,202, 206,213,217,226] / [6,20,43,44]
Iron-Nickel (see Taenite)	(Fe, Ni)										
Iron-Silicon	$Fe_{12}Si$	7.641	3.87	0.04	1.67	0.02	0.984	3.568	2	37	[42,121]
Iron-Silicon	Fe_7Si	7.49	4.01	0.06	1.71	0.04	0.975	2.291	2	3	[121]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_o (km/sec)	error ΔC_o (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Iron-Silicon (see Suessite)	Fe_3Si										
Lead	Pb	4.71	0.31	--	1.42	--	0.607	1.016	2	2	
			0.17	0.06	1.59	0.03	1.016	2.83	3	5	
			0.78	0.12	1.37	0.03	2.83	5.77	4	3	[209]
Lead	Pb	6.79	0.555	0.016	1.726	0.015	0.55	1.44	2	4	
			0.94	0.05	1.462	0.018	1.44	3.24	3	3	
			1.36	--	1.33	--	3.24	4.85	4	2	[209]
Lead	Pb	8.40	0.71	0.07	2.10	0.14	0.26	0.73	2	3	
			1.15	0.08	1.59	0.05	0.73	2.18	3	6	
			1.84	0.05	1.306	0.016	2.18	4.91	4	5	[209]
Lead	Pb	9.51	1.20	0.07	1.87	0.08	0.46	1.16	2	3	
			1.58	0.05	1.51	0.02	1.16	2.73	3	3	[209]
Lead	Pb	11.345	1.992	0.014	1.511	0.012	0	2.36	2	93	
			2.70	0.04	1.213	0.006	2.335	19.12	4	42	[25,28,30,33,121, 131,141,163,166, 206,213,217,226]
Mercury	Hg	13.54	1.45	--	2.26	--	0	0.56	2	2	
			1.752	0.007	1.724	0.009	0.56	0.991	4	3	[121,225]
Nickel	Ni	1.644	-0.04	0.05	1.32	0.02	0.67	3.15	1	16	
			-0.4	0.3	1.47	0.06	2.86	5.73	2	19	[209]
Nickel	Ni	3.202	-0.09	0.07	1.71	0.02	1.53	4.045	2	6	
			0.87	0.17	1.46	0.02	4.045	10.31	4	3	[209]
Nickel	Ni	4.198	0.02	0.13	1.88	0.05	0.61	3.86	2	15	[209]
Nickel	Ni	5.15	0.7	--	1.9	--	1.23	1.98	2	2	
			1.40	0.09	1.606	0.019	1.98	8.91	4	7	[209]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Nickel	Ni	6.275	0.23	0.09	2.79	0.13	0.54	0.80	1	3	
			1.02	0.10	2.03	0.05	0.80	3.28	2	9	
			2.15	--	1.64	--	3.28	4.62	4	2	[209]
Nickel	Ni	8.896	4.57	0.04	0.29	0.17	0	0.354	1	4	
			3.83	0.17	2.5	0.3	0.349	0.635	2	28	
			4.31	0.04	1.63	0.03	0.635	2.63	4a	52	
			5.41	0.08	1.300	0.015	2.63	7.5	4b	18	[24,25,90,121,131, 166,209,213,217, 226]
Palladium	Pd	11.996	3.83	0.02	1.83	0.04	0.00	0.825	2	7	
			4.09	0.05	1.49	0.03	0.803	2.317	4	13	[56,121,136,166, 217,226]
Platinum	Pt	21.445	3.587	0.014	1.556	0.008	0.00	3.444	2	29	[86,121,136,166, 217,226]
Rhenium	Re	20.53	4.12	0.05	-0.04	0.18	0.00	0.372	1	3	
			3.56	0.08	1.63	0.08	0.372	1.441	2	7	
			4.0	0.2	1.32	0.12	1.346	2.028	4	6	[121,136]
Rhenium	Re	20.984	4.16	0.04	1.40	0.06	0.00	1.127	2	7	[121,136]
Rhodium	Rh	12.422	4.28	0.12	2.7	0.4	0.00	0.426	1	4	
			4.76	0.05	1.41	0.04	0.369	2.004	2	14	
			4.043	0.018	1.713	0.006	2.004	3.8	4	3	[24,121,136,166, 226]
Silver	Ag	10.49	3.23	0.04	1.59	0.03	0.00	2.149	2	16	
			3.56	0.13	1.46	0.04	2.12	4.32	4	9	[24,30,56,121,131, 166,217,226]
Suessite	$(Fe,Ni)_3Si$	6.870	5.21	--	2.25	--	0.00	0.495	1	2	
			5.53	0.06	1.23	0.03	0.495	3.627	2	32	[42,121]
Sulfur	S	2.02	3.633	0.013	0.606	0.010	0.897	1.470	2	3	
			2.8	0.3	1.18	0.15	1.431	2.046	4	6	[121]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Taenite (also Kamacite)	(Fe,Ni)	7.933	4.41	0.05	1.01	0.05	0.00	1.09	1	11	
			3.79	0.051	1.65	0.02	1.019	2.777	2	41	
			4.20	0.17	1.48	0.05	2.723	4.59	4	11	[36,121,132,136, 217]
Tin	Sn	7.299	2.60	0.15	2.2	0.9	0.00	0.304	1	3	
			3.33	0.07	-0.14	0.15	0.304	0.5	3	6	
			2.48	0.03	1.57	0.03	0.5	2.15	2	66	
			3.43	0.03	1.205	0.008	2.15	8	4	33	[24,25,30,121,126, 131,166,213,217, 226]
Wairauite	CoFe	8.091	4.64	0.04	1.63	0.08	0.00	0.647	2	12	
			5.69	0.02	-0.10	0.02	0.663	1.037	3	5	
			3.78	0.08	1.62	0.04	1.038	2.801	4	10	[121]
Zinc	Zn	6.51	3.69	0.17	0.98	0.12	0.54	2.08	2	3	
			3.04	0.15	1.35	0.05	2.08	5.04	4	4	[23]
Zinc	Zn	7.138	3.00	0.02	1.586	0.013	0.00	3.01	2	39	
			3.70	0.15	1.37	0.04	2.98	4.85	3	10	
			4.05	0.02	1.303	0.003	4.85	8	4	9	[24,25,30,121,126, 131,166,217,224, 226]
Carbides:											
Moissanite	SiC	2.333	2.3	0.3	1.84	0.12	2.048	3.444	4	10	[121,127,136]
Moissanite	SiC	3.029	8.4	0.6	0.3	0.3	1.535	2.112	3	3	
			5.6	0.3	1.62	0.14	2.112	2.842	4	4	[121]
Moissanite	SiC	3.122	8.0	--	6.0	--	0.00	0.464	1	2	
			10.29	0.13	-0.38	0.10	0.674	1.678	3	9	
			7.84	0.11	1.03	0.05	1.678	2.912	4	10	[121,127,136]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Tantalum Carbide	TaC	12.626	3.32	0.09	1.49	0.05	0.887	2.619	2	20	[121]
Tantalum Carbide	TaC	14.110	4.34	0.05	1.36	0.03	0.435	3.76	2	21	[121,152]
Tungsten CarbideP	WC	15.013	4.97	0.11	2.1	0.4	0.00	0.369	1	4	
			5.21	0.03	1.14	0.02	0.369	1.819	2	12	[121,127,136]
Tungsten Carbide	WC	15.66	4.926	0.014	1.163	0.007	0.45	3.66	2	4	[152]
Sulfides:											
Sphalerite	ZnS	3.952	5.08	0.03	-0.09	0.03	0.63	1.52	2	3	
			3.10	0.10	1.22	0.04	1.52	2.70	3	3	
			0.9	--	2.0	--	2.70	3.56	4	2	[186]
Pyrrhotite	$Fe_{1-x}S$	4.605	5.8	0.2	-4.7	0.5	0.235	0.547	1	3	
			2.31	0.17	2.08	0.15	0.494	1.599	2	10	
			3.23	0.10	1.49	0.03	1.496	5.361	4	14	[3,53]
Pyrite	FeS_2	4.933	8.8	1.0	-1.4	1.0	0.225	1.39	1	7	
			5.3	0.10	1.47	0.04	1.133	5	2	11	[10,186]
Potassium Iron Sulfide	$KFeS_2$	2.59	2.32	0.06	1.97	0.05	0.223	2.05	2	11	
			8.2	--	-1.0	--	2.05	2.79	3	2	
			0.25	0.07	1.912	0.017	2.79	4.72	4	3	[191,230]
Halides:											
Griceite	LiF	1.27	0.74	--	1.58	--	2.4	6.59	2	2	[106]
Griceite	LiF	2.638	5.10	0.09	1.35	0.03	0.452	10.01	2	68	[38,54,121,195,213] /[177]
Villiaumite	NaF	2.792	4.08	0.14	1.42	0.13	0.5	1.54	2	8	
			6.7	0.3	-0.28	0.16	1.54	2.027	3	4	
			2.83	0.04	1.635	0.013	2.027	3.982	4	8	[54,213]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_o (km/sec)	error ΔC_o (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Halite	NaCl	0.868	-0.15	0.19	1.72	0.06	1.942	3.62	2a	4	
			7.0	1.3	-0.2	0.3	3.62	4.181	3	3	
			-0.4	--	1.5	--	4.181	5.552	2b	2	[121]
Halite	NaCl	0.989	0.74	0.09	1.470	0.018	2.53	6.02	2	5	
			3.9	--	0.9	--	6.02	6.6	3	2	
			-17.0	--	4.1	--	6.6	6.7	4	2	[106]
Halite	NaCl	1.427	1.56	0.12	1.49	0.03	2.29	5.66	2	5	
			5.6	--	0.8	--	5.66	6	3	2	
			-5.1	--	2.5	--	6	6.11	4	2	[106]
Halite	NaCl	2.159	3.60	0.09	1.17	0.18	0.00	0.647	1	28	
			3.41	0.03	1.42	0.03	0.646	1.7	2a	113	
			4.35	0.09	0.88	0.04	1.7	2.5	3a	109	
			2.43	0.07	1.66	0.02	2.5	3.75	4a	95	
			4.4	0.3	1.11	0.08	3.73	4.356	3b	43	
			3.5	0.3	1.33	0.05	4.324	6.52	4b	8	
			19	--	-1	--	6.52	6.8	3c	2	
			3.8	0.2	1.18	0.02	6.8	11.05	4c	3	[32,73,84,106,121, 213] /[48, 103, 107, 176, 177]
Sylvite	KCl	0.79	0.9	--	1.3	--	2.66	7.19	2	2	[106]
Sylvite	KCl	1.41	1.9	--	1.3	--	2.3	6.56	2	2	[106]
Sylvite	KCl	1.986	2.86	0.09	1.26	0.09	0.249	2.2	1	33	
			4.0	0.2	1.09	0.05	2.2	6.71	2	9	
			14	--	-0.4	--	6.71	7.1	3	2	
			2.5	0.4	1.25	0.04	7.1	11.38	4	3	[34,38,85,106,213] /[48,107,177]
Potassium Bromide	KBr	2.747	2.83	0.16	-0.1	0.3	0.27	0.61	1	4	
			1.88	0.05	1.50	0.03	0.57	2.9	2	13	
			2.63	0.09	1.24	0.02	2.862	5.09	4a	12	
			3.23	0.19	1.11	0.03	5.09	10.6	4b	6	[38,106,121,213] / [48]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Cesium Iodide	CsI	2.51	0.66	0.12	1.42	0.04	1.04	4.23	2	6	
			1.37	0.12	1.22	0.02	4.23	6.75	4	4	[154]
Cesium Iodide	CsI	4.51	1.57	0.17	1.66	0.17	0.56	1.32	2	7	
			3.8	--	0.1	--	1.32	1.56	3	2	
			1.95	0.05	1.302	0.019	1.56	4.3	4a	13	
			2.66	0.13	1.141	0.019	4.3	9.28	4b	3	[38,121,154,213] /[199,209]
Fluorite	CaF_2	3.18	5.5	--	0.8	--	1.1	2.22	1	2	
			4.64	0.16	1.19	0.06	2.22	3.38	2	4	
			8.2	--	0.14	--	3.38	3.67	3	2	
			0.4	0.3	2.27	0.07	3.67	5.76	4	5	[35]
Cryolite	Na_3AlF_6	2.96	4.70	0.10	0.89	0.09	0.71	1.57	2	3	
			3.76	0.12	1.44	0.04	1.57	3.8	4	4	[186]
Oxides:											
Water, Ice[j]	H_2O	0.35	0.080	0.18	1.40	0.03	2.76	6.75	2	5	[41]
Water, Ice[j]	H_2O	0.60	0.83	0.16	1.40	0.03	2.57	6.2	2	5	[41]
Water, Ice[j]	H_2O	0.915	4.05	0.05	-1.89	0.16	0.045	0.858	1	7	
			1.43	0.11	1.48	0.03	0.858	5.67	2	9	[41,75,114]
Water, Ice[k]	H_2O	0.999	1.47	0.04	1.93	0.06	0.00	0.97	1	14	
			1.70	0.06	1.71	0.03	0.9	2.53	2	58	
			2.64	0.07	1.270	0.008	2.479	32.42	4	25	[19,29,116,121,140, 157,167,213,217, 225] / [87,119]
Seawater	(mixture)	1.03	1.69	0.08	1.73	0.10	0.31	1.11	2	3	
			2.07	0.09	1.38	0.03	1.11	4.76	4	4	[210]
Bromellite	BeO	2.454	3.5	0.3	1.92	0.12	1.799	3.356	2	6	[120,121]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_o (km/sec)	error ΔC_o (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Bromellite	BeO	2.661	8.5	--	-1.2	--	0.577	1.25	1	2	
			5.4	0.8	1.6	0.4	1.25	3.46	2	3	[120,121,213]
Bromellite	BeO	2.797	9.10	0.18	-1.0	0.2	0.368	1.094	1	4	
			6.7	0.5	1.32	0.18	1.094	3.71	2	5	[120,121,213]
Bromellite	BeO	2.886	7.76	0.10	1.22	0.05	0.77	2.74	2	12	
			8.42	0.06	1.042	0.013	2.74	5.78	4	3	[120,121,152,213]
Bromellite	BeO	2.989	10.84	0.08	-0.78	0.13	0.317	0.939	1	4	
			9.65	0.10	0.49	0.07	0.939	1.825	2	4	
			7.7	0.3	1.53	0.11	1.825	2.822	4	4	[120,121]
Periclase	MgO	2.842	2.8	0.2	1.84	0.08	1.749	3.528	2	6	[56,121,127]
Periclase	MgO	3.00	3.10	0.14	1.88	0.06	1.259	3.362	2	13	[56,121,127]
Periclase	MgO	3.355	3.5	0.3	2.7	0.3	0.629	1.557	2a	8	
			4.78	0.13	1.77	0.06	1.509	2.652	2b	9	
			5.73	0.12	1.36	0.03	2.619	5.62	4	11	[37,56,121,127]
Periclase	MgO	3.583	6.09	0.10	1.75	0.08	0.626	1.967	2	25	
			6.83	0.12	1.29	0.04	1.92	4.44	4	16	[2,47,56,76,121, 127,217,218] /[197]
Magnesio-wüstite	$Mg_{0.6}Fe_{0.4}O$	4.397	4.81	0.04	1.63	0.02	1.55	2.3	2	3	
			6.50	0.16	0.91	0.05	2.3	3.33	3b	4	
			4.6	0.7	1.51	0.17	3.33	4.29	4	4	[219]
Magnesio-wüstite	$Mg_{0.1}Fe_{0.9}O$	5.191	4.3	--	5.7	--	0.00	0.332	1	2	
			6.27	0.11	-0.3	0.2	0.332	0.705	3a	3	
			4.96	0.07	1.56	0.07	0.705	1.28	2	3	
			5.53	0.12	1.14	0.07	1.28	2.169	3b	4	
			4.76	0.14	1.49	0.06	2.169	2.721	4	3	[121]
Lime	CaO	2.980	3.56	0.11	1.79	0.07	0.882	2.083	2	6	
			6.7	0.6	0.3	0.2	2.083	3.01	3	3	
			2.61	0.16	1.67	0.05	3.01	3.558	4	5	[121]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_o (km/sec)	error ΔC_o (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Lime	CaO	3.324	7.4	0.8	0.5	0.3	1.801	3.285	3	5	
			4.2	1.2	1.5	0.3	3.285	4.628	4	9	[97] / [50]
Wüstite	$Fe_{1-x}O$	5.548	4.80	0.10	1.33	0.07	1.22	1.766	2	3	
			6.9	--	0.2	--	1.766	2.034	3	2	
			3.72	0.15	1.59	0.04	2.414	4.055	4	4	[97]
Wüstite	$Fe_{1-x}O$	5.662	3.4	--	2.4	--	1.56	1.73	2	2	
			6.84	0.02	0.408	0.011	1.73	2.51	3	3	
			3.3	--	1.8	--	2.51	2.62	4	2	[232]
Corundum	Al_2O_3	3.761	11.04	0.18	-4.3	0.5	0.18	0.706	1	7	
			6.61	0.16	1.35	0.07	0.706	3.282	2	15	[9,121,127]
Corundum	Al_2O_3	3.843	10.20	0.125	-1.9	0.3	0.18	0.898	1	5	
			7.08	0.11	1.36	0.05	0.898	2.979	2	10	[47,121,122,127, 217]
Corundum	Al_2O_3	3.92	8.71	0.05	0.716	0.017	0.37	5.5	2	6	[152]
Corundum	Al_2O_3	3.979	11.04	0.07	1.1	0.3	0.033	0.46	0	41	
			17.8	1.6	-14	3	0.46	0.621	1	6	
			8.83	0.06	0.93	0.03	0.555	3.064	2	52	[9,47,78,121,122, 127,217]
Corundum	Al_2O_3	4.00	9.52	0.04	0.955	0.008	1.02	8.28	2	4	[152]
Hematite	α-Fe_2O_3	5.047	6.18	0.12	1.40	0.17	0.00	1.03	2	6	
			7.435	0.011	0.035	0.007	1.097	2.294	3	4	
			4.39	0.11	1.37	0.04	2.294	3.18	4	10	[47,121,127,200, 217]
Ilmenite	$Fe^{+2}TiO_3$	4.75	5.85	0.08	1.28	0.07	0.85	1.38	2	3	
			7.43	--	0.13	--	1.38	1.92	3	2	
			5.46	--	1.15	--	1.92	3.09	4	2	[186]
Ilmenite	$Fe^{+2}TiO_3$	4.787	6.33	0.12	1.0	0.2	0.00	0.652	2	3	

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_o (km/sec)	error ΔC_o (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
			6.86	0.06	0.17	0.05	0.626	2.009	3	5	
			4.07	0.18	1.54	0.07	2.009	3.082	4	12	[121,127]
Perovskite	$CaTiO_3$	3.86	5.25	0.11	1.48	0.07	0.59	2.35	2	5	
			6.5	0.3	0.93	0.10	2.35	3.24	3	3	
			4.0	--	1.7	--	3.24	5.42	4	2	[187]
Barium Titanate	$BaTiO_3$	5.447	6.26	0.14	-4.0	0.3	0.016	0.655	1	23	
			2.33	0.10	2.63	0.10	0.533	1.334	2	55	
			3.7	0.2	1.60	0.12	1.321	2.479	4	9	[66,121,213]
Spinel	$MgAl_2O_4$	2.991	4.05	0.19	1.43	0.07	1.727	3.63	4	9	[121,127]
Spinel	$MgAl_2O_4$	3.417	7.1	--	1.13	--	0.00	0.987	2	2	
			8.23	0.06	-0.03	0.03	0.987	2.146	3	10	
			5.07	0.16	1.42	0.06	2.134	3.348	4	13	[47,121,127,217]
Spinel	$MgAl_2O_4$	3.514	7.26	0.07	1.48	0.17	0.00	0.688	2	3	
			8.04	0.07	0.27	0.04	0.688	2.311	3	5	
			5.7	0.5	1.35	0.16	2.311	3.507	4	8	[121,127]
Magnetite	$Fe^{+2}Fe^{+3}{}_2O_4$	5.07	7.2	--	-0.2	--	1.14	1.5	3	2	
			3.0	1.4	1.8	0.4	2.72	4.52	4	3	[186]
Magnetite	$Fe^{+2}Fe^{+3}{}_2O_4$	5.117	5.9	--	1.3	--	0.00	0.61	2	2	
			6.56	0.08	0.05	0.06	0.61	1.786	3	10	
			4.24	0.11	1.36	0.05	1.757	2.975	4	15	[47,121,127,217]
Rutile	TiO_2	4.21	6.96	0.06	0.23	0.03	1.14	2.44	3	3	
			2.1	0.3	2.15	0.08	2.44	5.2	4	5	[35]
Rutile	TiO_2	4.245	10.3	0.5	-4.3	1.3	0.09	0.676	1	11	
			7.68	0.11	0.21	0.07	0.468	2.858	3	8	
			3.0	0.6	1.8	0.2	2.858	3.191	4	8	[11,47,121,123,127, 130,217]
Pyrolusite	$Mn^{+4}O_2$	4.318	3.77	0.14	1.46	0.07	0.769	3.263	2	16	[47,121,217]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Cassiterite	SnO_2	6.694	6.82	0.05	-0.22	0.05	0.509	1.866	1	7	
			5.15	0.06	0.68	0.03	1.866	2.501	2	4	
			2.6	0.6	1.7	0.2	2.501	2.833	4	3	[47,121,217]
Argutite	GeO_2	6.277	9.51	0.12	0.29	0.11	0.15	2.57	2	6	[92]
Baddeleyite	ZrO_2	4.512	4.4	--	0.27	--	0.00	1.622	2	2	
			1.9	0.4	1.88	0.17	1.622	2.994	4	8	[121]
Baddeleyite	ZrO_2	5.814	5.17	0.08	1.02	0.05	0.41	2.17	2	4	
			4.42	0.07	1.35	0.03	2.17	2.99	4	4	[124]
Cerianite	$(Ce^{+4},Th)O_2$	1.133	0.2	0.3	1.20	0.07	1.925	5.437	2	7	[121]
Uraninite	UO_2	10.337	3.99	0.06	0.20	0.13	0.00	0.571	1	3	
			3.59	0.04	0.91	0.03	0.568	1.983	2	12	
			1.7	0.4	1.8	0.16	1.983	2.493	4	6	[121]
Uraninite	UO_2	6.347	0.43	0.07	1.70	0.03	1.025	3.286	4	18	[121]
Uraninite	UO_2	4.306	0.12	0.11	1.51	0.04	0.88	3.855	4	15	[121]
Uraninite	UO_2	3.111	-0.22	0.10	1.47	0.03	1.355	4.256	4	15	[121]
Hydroxides:											
Brucite	$Mg(OH)_2$	2.37	4.75	0.06	1.26	0.02	1.25	3.41	2	6	
			0.9	--	2.4	--	3.41	3.96	4	2	[186]
Brucite	$Mg(OH)_2$	2.383	5.0	0.2	1.22	0.11	0.886	3.079	2	13	[69]
Goethite	α-$Fe^{+3}O(OH)$	4.0	4.4	--	1.6	--	1.02	1.34	2	2	
			5.77	0.11	0.61	0.06	1.34	2.52	3	3	
			2.9	--	1.8	--	2.52	3.51	4	2	[187]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Carbonates:											
Calcite	$CaCO_3$	2.701	6.9	0.2	-2.8	1.0	0.081	0.81	1	24	
			3.71	0.03	1.435	0.013	0.81	3.845	2	6	[11,21,102] / [103]
Magnesite	$MgCO_3$	2.975	6.08	0.09	1.26	0.04	0.6	3.61	2	6	[102]
Dolomite	$CaMg(CO_3)_2$	2.828	6.2	0.5	0.4	0.5	0.495	1.15	2	5	
			5.30	0.10	1.16	0.03	1.12	5.32	4	19	[102,184,213]
Aragonite	$CaCO_3$	2.928	5.82	0.11	0.78	0.12	0.11	1.83	2	12	[220]
Sulfates:											
Mascagnite	$(NH_4)_2SO_4$	1.3	0.77	0.15	2.28	0.167	0.36	1.21	2	8	
			1.8	0.2	1.54	0.12	1.15	2.5	4	11	[99]
Mascagnite	$(NH_4)_2SO_4$	1.6	1.96	0.10	2.09	0.10	0.28	1.83	2	8	[99]
Mascagnite	$(NH_4)_2SO_4$	1.73	3.71	0.14	1.34	0.12	0.2	1.87	2	5	[99]
Anhydrite	$CaSO_4$	2.97	3.60	0.06	1.75	0.05	0.73	1.55	2	3	
			4.6	--	1.1	--	1.55	1.85	3	2	
			3.24	0.11	1.72	0.03	2.42	3.71	4	4	[186]
Barite	$BaSO_4$	4.375	3.3	--	1.9	--	0.64	1.03	2	2	
			4.7	0.2	0.54	0.15	1.03	1.69	3	3	
			2.3	0.4	1.86	0.16	1.69	3.29	4	5	[186]
Gypsum	$CaSO_4 \cdot 2H_2O$	2.28	2.80	0.17	1.95	0.13	0.85	1.72	2	3	
			5.2	--	0.5	--	1.72	2.15	3	2	
			2.49	0.12	1.79	0.04	2.15	4.06	4	5	[186] / [103]
Borates:											
Sassolite	H_3BO_3	1.471	2.09	0.11	1.27	0.08	1.254	1.639	2	3	
			1.14	--	1.85	--	1.639	2.114	4	2	[121]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Silica Polymorphs:											
Quartz	SiO_2	2.651	6.61	0.12	1.02	0.19	0.295	0.81	0a	16	
			5.65	0.09	0.9	0.2	0.285	0.66	0b	29	
			8.14	0.11	-1.32	0.12	0.508	1.815	1a	16	
			6.44	0.07	-0.43	0.08	0.48	1.815	1b	12	
			5.29	0.08	0.20	0.04	1.803	2.48	3a	6	
			1.48	0.10	1.80	0.03	2.46	4.55	2	24	
			8.2	0.6	0.33	0.12	4.51	4.84	3b	3	
			4.0	0.2	1.283	0.018	4.84	26.76	4	10	[11,17,27,37,47,72, 118,121,127,129, 155,162,208,217, 222] / [118,165]
Porous Quartz	SiO_2	1.15	0.41	0.09	1.40	0.03	1.52	5.28	2	15	[188,207]
Porous Quartz	SiO_2	1.43	0.87	0.09	1.38	0.03	0.65	5.08	2	30	[188,207]
Porous	SiO_2	1.766	1.27	0.03	1.356	0.019	0.62	2.13	2	4	
Quartz			3.42	0.13	0.34	0.05	2.13	2.55	3	3	
			0.25	0.05	1.589	0.011	2.55	9.0	4	9	[188,207]
Porous	SiO_2	1.877	2.75	0.07	0.82	0.03	0.849	3.374	2	11	
Quartz			-0.5	0.4	1.86	0.10	3.374	4.863	4	15	[121]
Porous	SiO_2	2.151	3.02	0.16	0.84	0.08	0.799	3.199	2	11	
Quartz			0.7	0.2	1.67	0.06	3.199	6.52	4	16	[121,207]
Silicic Acid	H_4SiO_4	0.55	-0.09	0.11	1.27	0.02	3.51	6.59	4	5	[188]
Silicic Acid	H_4SiO_4	0.65	-0.01	0.03	1.275	0.006	2.94	5.93	4	6	[188]
Silicic Acid	H_4SiO_4	0.80	0.78	0.03	1.05	0.02	0.68	1.98	2	3	
			0.33	0.04	1.261	0.009	1.98	5.71	4	7	[188]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Aerogel	SiO_2^r	0.172	0.21	0.07	1.01	0.02	1.494	4.01	2	6	
			-0.44	0.10	1.164	0.018	4.01	7.401	4	8	[88,188]
Aerogel	SiO_2^r	0.295	0.21	0.03	1.11	0.05	0.302	0.765	2	3	[158]
Aerogel	SiO_2^r	0.40	0.29	0.03	1.089	0.010	1.456	3.63	2	4	
			-0.214	0.013	1.224	0.003	3.63	6.37	4	4	[188]
Aerogel	SiO_2^r	0.55	0.590	0.006	0.945	0.006	0.335	1.43	2	3	
			0.15	0.04	1.219	0.008	1.43	6.1	4	7	[188]
Cristobalite	SiO_2	2.13	2.29	0.09	1.01	0.06	0.96	1.99	2	3	
			1.23	0.05	1.545	0.014	1.99	4.66	4	6	[156]
Coesite	SiO_2	1.15	0.44	0.07	1.44	0.02	1.2	4.59	2	5	[156]
Coesite	SiO_2	2.40	3.4	0.3	1.42	0.19	1.33	2.05	2	3	
			4.3	--	0.97	--	2.05	4.16	3	2	[156]
Coesite	SiO_2	2.92	5.833	0.010	0.902	0.009	0.66	1.48	2	3	
			6.92	0.02	0.168	0.011	1.48	2.86	3	3	
			2.6	0.4	1.68	0.12	2.86	4.05	4	3	[156]
Silicates:											
Forsterite	Mg_2SiO_4	3.059	5.71	0.07	0.64	0.03	0.825	2.771	2	6	
			3.0	0.3	1.65	0.10	2.771	3.626	4	6	[47,121,127,217]
Forsterite	Mg_2SiO_4	3.212	10.5	0.2	-3.8	0.4	0.18	0.797	1a	16	
			6.8	0.3	1.4	0.6	0.00	0.795	1b	12	
			7.21	0.10	0.55	0.06	0.749	2.449	2	20	
			4.6	0.3	1.51	0.08	2.433	4.61	4	20	[91,121,127,201, 229] / [165]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Olivine	$(Mg,Fe)_2SiO_4$; $(Mg_{0.92}Fe_{0.08})_2SiO_4$	3.264	8.84	0.13	-0.99	0.18	0.272	1.43	1	4	
			5.6	--	1.3	--	1.43	2.19	2	2	
			8.1	--	0.15	--	2.19	2.8	3	2	
			6.0	0.3	0.88	0.08	2.8	4.81	4	3	[15,121]
Fayalite	Fe_2SiO_4	4.245	6.17	0.09	0.23	0.06	0.702	1.967	2	10	
			3.78	0.13	1.42	0.05	1.967	3.483	4	10	[47,121,127,217]
Zircon	$ZrSiO_4$	4.549	8.58	0.18	-1.3	0.4	0.11	1.07	1	7	
			7.14	0.05	0.02	0.03	1.07	2.52	3	4	
			-1.6	0.9	3.5	0.3	2.52	2.84	2	4	[124]
Almandine	$(Fe_{0.79}Mg_{0.14}Ca_{0.04}Mn_{0.03})_3Al_2Si_3O_{12}$	4.181	-10	--	50	--	0.29	0.32	1	2	
			5.92	0.07	1.39	0.08	0.45	1.14	2	8	
			3.0	--	3.6	--	1.29	1.46	3	2	
			6.4	0.3	1.33	0.16	1.46	1.8	4	7	[77]
Grossular	$Ca_3Al_2Si_3O_{12}$	3.45	8.3	0.17	0.47	0.10	0.18	3.04	2	16	[121]
Mullite	$Al_6Si_2O_{13}$	2.668	2.30	0.13	1.65	0.04	1.935	4.077	2	13	[121,127]
Mullite	$Al_6Si_2O_{13}$	3.154	8.732	0.016	-0.394	0.015	0.717	1.479	1	3	
			8.29	0.04	-0.09	0.02	1.479	2.003	3	3	
			6.5	--	0.78	--	2.003	3.311	4	2	[121]
Kyanite	Al_2SiO_5	2.921	7.45	0.06	-0.58	0.07	0.608	1.157	1	3	
			7.02	0.09	-0.19	0.05	1.157	2.359	3	5	
			2.2	0.3	1.85	0.10	2.359	3.383	4	5	[121]
Kyanite	Al_2SiO_5	3.645	7.8	--	0.6	--	1.537	2.745	2	2	
			3.9	1.7	2.0	0.6	2.745	3.22	4	3	[121]
Andalusite	Al_2SiO_5	3.074	5.3	--	1.9	--	0.00	1.1	2	2	
			6.92	0.15	0.31	0.07	1.1	2.817	3	12	
			2.9	0.4	1.80	0.13	2.817	3.73	4	8	[47,121,217]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Sillimanite	Al_2SiO_5	3.127	6.97	0.15	0.68	0.16	0.00	1.262	1	3	
			7.8	0.2	-0.10	0.11	1.068	2.461	3	8	
			3.8	0.2	1.57	0.08	2.461	3.611	4	10	[47,121,217]
Topaz	Al_2SiO_4-$(F,OH)_2$	3.53	8.10	0.09	0.054	0.08	0.052	1.75	1	4	
			5.3	0.4	1.722	0.15	1.75	3.59	2	6	[186]
Tourmaline	Ca(Al,Fe,-Mg)$_3Al_6Si_6$-$O_{18}(OH,F)_4$	3.179	6.2	--	1.2	--	0.824	1.555	1	2	
			8.1	0.4	0.05	0.15	1.555	2.888	3	7	
			3.6	0.5	1.62	0.16	2.888	3.695	4	8	[121]
Muscovite	$KAl_2(Si_3Al)$-$O_{10}(OH,F)_2$	2.835	3.3	0.3	1.95	0.16	1.27	2.44	2	3	
			6.2	--	0.7	--	2.44	3.18	3	2	
			4.5	0.2	1.29	0.06	3.18	4.74	4	4	[182]
Serpentine	Mg_3Si_2-$O_5(OH)_4$	2.621	5.30	0.15	0.90	0.11	0.431	2.025	2	10	
			6.5	0.4	0.20	0.18	1.719	2.561	3	10	
			3.8	0.5	1.34	0.12	2.658	5.427	4	16	[47,121,211,217]
Pyroxenes:											
Enstatite	Mg_2-Si_2O_6	2.714	2.70	0.11	1.31	0.04	1.901	3.258	2	5	[47,121,217]
Enstatite	Mg_2-Si_2O_6	2.814	2.74	0.14	2.04	0.09	0.746	1.956	2	5	
			6.8	--	-0.1	--	1.956	2.128	3	2	
			3.64	0.16	1.43	0.05	2.128	3.946	4	9	[121,127]
Enstatite	Mg_2-Si_2O_6	3.067	8.11	0.18	-1.5	0.4	0.224	0.60	1	6	
			4.98	0.13	1.18	0.09	0.456	2.126	2	19	
			7.4	0.4	-0.1	0.2	1.817	2.349	3	6	
			3.7	0.3	1.54	0.07	2.349	4.54	4	22	[8,121,127,231] / [117,165]
Diopside	$CaMgSi_2O_6$	3.264	4.9	--	8.4	--	0.201	0.289	1	2	
			7.14	0.03	0.626	0.018	0.289	1.85	2	4	
			6.1	0.2	1.16	0.06	1.85	4.7	4	4	[18,196,213] / [198]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Beryl	$Be_3Al_2Si_6O_{18}$	2.68	8.83	0.10	0.05	0.04	1.4	4.12	2	4	
			2.7	--	1.6	--	4.12	6.1	4	2	[187]
Feldspars:											
Orthoclase, Microcline	$KAlSi_3O_8$	2.561	7.70	0.11	-1.1	0.2	0.188	1.21	1	14	
			6.14	0.19	0.21	0.11	1.21	2.41	2	4	
			3.1	0.2	1.39	0.05	2.41	6.27	4	4	[12,16,186]
Oligoclase	$(NaAlSi_3O_8)_{75}(CaAl_2Si_2O_8)_{19.5}$ - $(KAlSi_3O_8)_{5.5}$	2.635	7.6	0.3	-1.5	1.2	0.195	0.3	1	13	[16]
Anorthite	$CaAl_2Si_2O_8$	2.769	3.17	0.16	1.45	0.04	2.911	4.338	2	3	[96] / [173,174]
Molten Anorthite°	$CaAl_2Si_2O_8$	2.55	2.85	0.14	1.27	0.09	0.91	2.37	2	6	[168]
Nepheline	$(Na,K)AlSiO_4$	2.63	4.76	0.08	0.88	0.09	0.52	1.25	2	3	
			5.7	--	0.1	--	1.25	1.62	3	2	
			2.22	0.08	1.67	0.02	2.57	3.94	4	4	[187]
Glasses:											
Argutite Glass	GeO_2	3.655	3.6	--	-0.3	--	0.32	1.35	1	2	
			0.80	0.06	1.79	0.02	1.35	4.46	2	7	[92]
Quartz Glass (fused quartz)	SiO_2	0.145	1.8	--	0.36	--	1.789	2.309	2	2	
			-1.2	0.3	1.67	0.05	2.309	6.507	4	10	[121]
Quartz Glass	SiO_2	1.15	0.09	0.2	1.51	0.06	3.07	5.21	4	4	[156]
Quartz Glass	SiO_2	2.2	0.4	0.5	1.73	0.12	3.61	4.84	4	6	[91]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Molten Diopside[n]	$CaMgSi_2O_6$	2.61	3.30	0.12	1.44	0.08	0.73	2.24	2	5	[168]
Hedenbergite	$CaFe^{+2}Si_2O_6$	3.42	2.8	--	2.8	--	1.1	1.41	2	2	
			6.1	--	0.47	--	1.41	2.42	3	2	
			3.30	0.05	1.620	0.018	2.42	3.62	4	3	[186]
Augite, also Salite	$(Ca_{0.80}Na_{0.03})(Mg_{0.76}Fe_{0.29}Ti_{0.03})(Al_{0.20}Si_{1.85})O_6$, $CaMg_{0.82}Fe_{0.18}Si_2O_6$	3.435	6.25	0.11	0.85	0.08	0.935	1.87	2	5	
			6.6	0.8	0.6	0.4	1.87	2.48	3	8	
			4.6	1.0	1.4	0.3	2.44	3.82	4	5	[18,196,213]
Jadeite	$Na(Al,Fe^{+3})Si_2O_6$	3.335	6.41	0.06	1.30	0.08	0.00	1.005	2a	3	
			6.57	0.10	1.09	0.07	0.986	1.94	2b	8	
			7.44	0.12	0.64	0.04	1.94	3.434	4	8	[47,121,135,217]
Spodumene	$LiAlSi_2O_6$	3.14	7.123	0.019	0.007	0.018	0.43	1.45	2	3	
			6.4	--	0.51	--	1.45	2.37	3	2	
			4.0	0.3	1.56	0.09	2.37	3.76	4	3	[187]
Wollastonite	$CaSiO_3$	2.82	2.4	0.3	1.65	0.08	1.34	4.06	4	6	[187]
Wollastonite	$CaSiO_3$	2.822	6.3	0.2	-0.15	0.15	0.94	1.799	3	5	
			4.1	0.2	1.07	0.09	1.799	2.778	4	4	[121]
Wollastonite	$CaSiO_3$	2.89	5.3	--	1.14	--	0.00	1.195	2	2	
			6.826	0.004	-0.156	0.003	1.195	1.933	3	3	
			4.52	0.15	1.03	0.06	1.933	3.282	4	5	[121]
Tremolite	$Ca_2(Mg,Fe^{+2})_5Si_8O_{22}(OH)_2$	2.901	5.20	0.14	0.91	0.07	1.15	2.82	2	9	
			3.2	0.8	1.6	0.2	2.78	3.94	4	5	[187]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Quartz Glass	SiO_2	2.204	5.83	0.03	-2.33	0.17	0.00	0.306	1	7	
			5.264	0.019	-0.114	0.014	0.306	2.106	3	32	
			3.40	0.08	0.78	0.03	2.063	2.742	2	20	
			0.80	0.08	1.70	0.02	2.703	5.175	4a	61	
			3.7	0.2	1.196	0.014	5.175	23.64	4b	3	[101,118,121,127, 129,163,217,222] / [104,117,118,175, 177]
Anorthite Glass	$CaAl_2Si_2O_8$	2.692	6.7	0.3	-0.2	0.4	0.45	1.179	1	5	
			6.43	0.14	0.01	0.07	1.179	2.731	3	3	
			1.8	0.3	1.77	0.07	2.731	4.698	4	15	[52] / [51]
Pyrex (and soda-lime glass)	$(SiO_2)_{81}$-$(B_2O_3)_{12}$-$(Al_2O_3)_{2.5}$-$(CaO)_{0.4}$-$(MgO)_{0.3}$-$(Na_2O)_4$-$(K_2O)_1$-$(As_2O_3)_{0.6}$[S]	2.307	5.26	0.14	-0.37	0.15	0.4	1.444	1	5	
			3.96	0.12	0.57	0.06	1.444	2.397	2	4	
			0.6	0.3	1.92	0.09	2.397	4.43	4	11	[95,121,122,136]
Soda-Copper Silicate Glass	$(SiO_2)_{72.2}$-$(CuO)_{12.4}$-$(Na_2O)_{14}$-$(Al_2-O_3)_{0.5}$-$(SO_3)_{0.45}$-$(MgO)_{0.1}$-$(Fe_2O_3)_{0.08}$[S]	2.48	3.10	0.04	1.28	0.08	0.37	0.71	2	3	
			3.623	0.012	0.531	0.009	0.71	1.55	3	3	
			1.5	0.2	1.95	0.11	1.51	2.57	4	5	[67]
Lunar Glass	$(SiO_2)_{40}$-$(TiO_2)_9$-$(Al_2O_3)_{11}$-$(FeO)_{17}$-$(MgO)_{10}$-$(CaO)_{11}$[S]	1.8	0.10	0.19	1.3	0.2	0.682	1.02	2	4	
			-1.01	0.13	2.39	0.09	0.985	1.825	4	6	[7]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Other Standards:											
Aluminum: 1100, Russian alloys	Al[r]	1.345	0.00 2.11	0.03 0.19	1.988 1.38	0.012 0.04	1.323 3.6	3.6 6.76	2 4	10 4	[105,142,213]
Aluminum: 1100, Russian alloys	Al[r]	1.885	0.8 3.07	0.4 0.11	2.2 1.39	0.2 0.03	1.197 2.70	2.77 6.27	2 4	12 6	[39,105,142,213]
Aluminum: 1100, Russian alloys	Al[r]	2.707	6.09 5.44 6.0	0.09 0.04 0.3	-0.1 1.324 1.181	0.4 0.012 0.019	0.01 0.428 5.94	0.526 6.0 30.0	1 2 4	10 59 27	[24,26,27,28,45, 105,115,121,139, 155,162,163,190, 213,228]
Aluminum 2024	Al[r]	1.661	2.20 0.18 2.0	0.12 0.15 0.2	0.19 2.20 1.54	0.15 0.08 0.06	0.00 0.983 2.739	1.012 2.739 4.567	1 2 4	3 9 15	[56,121,134,136]
Aluminum 2024	Al[r]	1.955	2.62 0.71 2.8	0.10 0.11 0.2	0.24 2.30 1.51	0.14 0.06 0.07	0.00 0.921 2.566	0.926 2.566 4.361	1 2 4	3 9 15	[56,121,134,136]
Aluminum 2024	Al[r]	2.224	3.0 1.3 3.22	-- 0.3 0.16	0.5 2.47 1.58	-- 0.19 0.05	0.00 0.849 1.981	0.849 2.124 4.064	1 2 4	2 7 17	[56,121,134,136]
Aluminum 2024	Al[r]	2.559	4.1 3.24 4.07	-- 0.18 0.10	0.9 2.04 1.54	-- 0.15 0.03	0.00 0.724 1.761	0.724 1.761 3.817	1 2 4	2 5 17	[56,121,134,136]
Aluminum 2024	Al[r]	2.788	5.356	0.011	1.305	0.005	0.00	5.962	2	325	[56,90,121,134,136, 166,213,217,224, 226] / [165]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Molybdenum	Mo	1.277	-0.03	0.06	1.25	0.03	0.678	4.05	2	5	[209]
Molybdenum	Mo	1.72	-0.39	0.10	1.40	0.03	3.02	5.01	2	4	[209]
Molybdenum	Mo	2.55	-0.12	0.05	1.473	0.013	0.654	6.51	2	10	[209]
Molybdenum	Mo	2.914	-0.16	0.04	1.538	0.012	0.65	6.3	2	10	[209]
Molybdenum	Mo	4.435	0.04	0.02	1.735	0.008	0.62	5.66	2	8	[209]
Molybdenum	Mo	5.59	0.30	0.06	1.90	0.02	0.3	5.25	2	13	[209]
Molybdenum	Mo	8.146	0.94 1.91 3.8	0.04 0.18 1.6	2.79 1.98 1.18	0.04 0.09 0.10	0.47 1.13 2.6	1.13 2.6 19.99	2 4a 4b	4 6 3	[162,163,209]
Molybdenum	Mo	10.208	5.14	0.03	1.247	0.005	0.00	20.91	2	61	[24,56,74,108,121, 126,131,136,141, 162,163,166,217, 226]
Molybdenum[m]	Mo	10.208	4.73	0.07	1.45	0.06	0.538	1.414	2	5	[137]
Tantalum	Ta	2.82	0.05 -0.33	0.04 0.03	1.26 1.451	0.03 0.010	0.654 2.06	2.06 4.43	2 4	4 3	[209]
Tantalum	Ta	5.41	-0.25	0.10	1.66	0.04	2.17	3.23	2	3	[209]
Tantalum	Ta	6.20	-0.01	0.02	1.649	0.012	0.601	2.37	2	5	[209]
Tantalum	Ta	8.19	0.028 0.54	0.018 0.09	1.891 1.61	0.012 0.04	1.15 1.8	1.8 3.03	2 4	3 6	[209]
Tantalum	Ta	10.92	0.37 1.43	0.10 0.08	2.23 1.52	0.09 0.04	0.7 1.49	1.49 2.64	2 4	3 5	[209]
Tantalum	Ta	16.649	3.31	0.03	1.306	0.010	0.00	5.86	2	31	[24,86,108,121,136, 139,166,217,226]

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.
Tungsten	W	4.6	-0.17	0.14	1.53	0.04	1.45	4.095	2	8	[209]
Tungsten	W	5.5	-0.08	0.07	1.54	0.03	1.38	2.76	2	4	
			0.4	--	1.4	--	2.76	3.63	3	2	
			-3.94	0.19	2.57	0.05	3.63	3.885	4	3	[209]
Tungsten	W	6.57	-0.011	0.013	1.584	0.007	1.295	2.35	2	3	
			1.07	--	1.12	--	2.35	2.68	3	2	
			-1.05	0.14	1.91	0.04	2.68	3.685	4a	4	
			1.7	0.5	1.21	0.04	3.685	16.51	4b	3	[204,209]
Tungsten	W	8.87	0.13	0.05	1.75	0.02	0.56	3.17	2	6	[209]
Tungsten	W	13.36	0.93	0.07	1.97	0.04	0.84	2.54	2	6	[209]
Tungsten	W	18.67	2.86	0.04	2.08	0.06	0.302	0.721	2	4	[121]
Tungsten	W	19.240	4.064	0.010	1.204	0.003	0.00	15.1	2	40	[100,121,131,136, 163,217]
Lexan	(polycarbon-ate)	1.193	1.9	--	2.4	--	0.00	0.421	1	2	
			2.38	0.03	1.551	0.019	0.421	2.53	2	32	
			4.47	0.12	0.70	0.04	2.379	3.651	3	21	
			2.6	0.2	1.27	0.05	3.64	6.92	4	19	[55,101,121]

Notes:

*Phases: 1) Elastic shock; 2) Low pressure phase; 3) Mixed region; 4) High pressure phase.

[a] Starting temperature 5K
[b] Starting temperature 20K
[c] Starting temperature 75-86K
[d] Starting temperature 111K
[e] Starting temperature 122K
[f] Starting temperature 148K; compressed gas
[g] Starting temperature 165K
[h] Starting temperature 196K

TABLE 1. Shock Wave Equation of State of Minerals and Related Materials of the Solar System

Mineral	Formula	Sample Density (Mg/m^3)	C_0 (km/sec)	error ΔC_0 (km/sec)	S	error ΔS	lower U_p (km/sec)	upper U_p (km/sec)	Phase*	No. of Data	References / Temp. Refs.

i Starting temperature 203-230K
j Starting temperature 258-263K
k Starting temperature 273-298K
l Starting temperature 300K; compressed gas
m Starting temperature 1673K
n Starting temperature 1773K
o Starting temperature 1923 K
p 5% cobalt
q raw data not provided
r with impurities
s composition in weight percent oxides

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